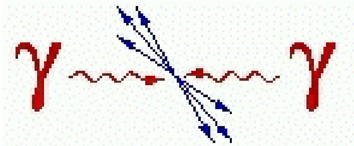
Measurements of the Photon Structure Function at LEP



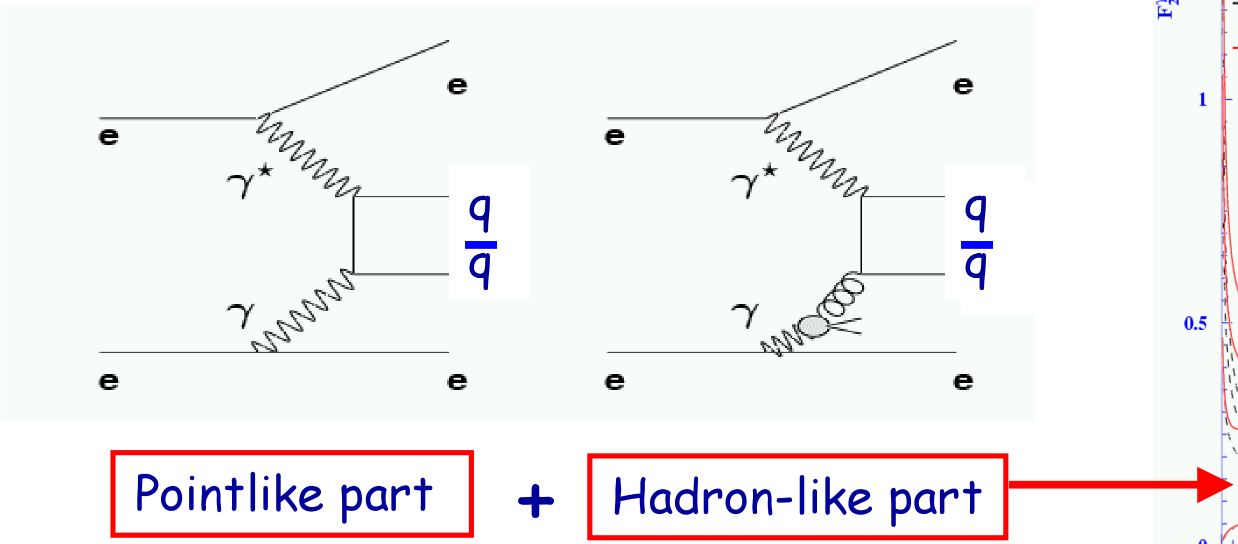
Albert De Roeck / CERN

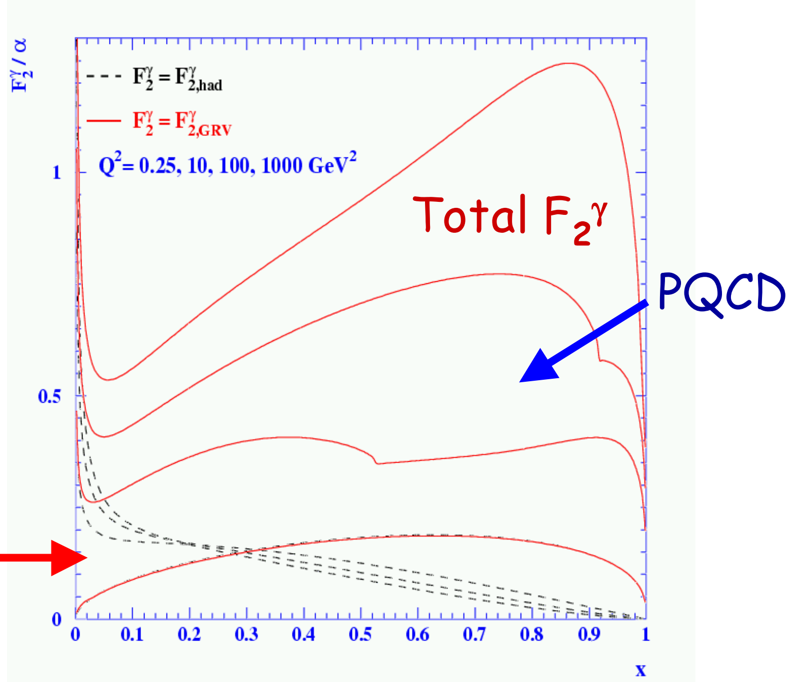
Representing the LEP Collaborations

HEP2003 Europhysics Conference

Aachen/Germany 17-23 July

New Photon Structure Function Developments



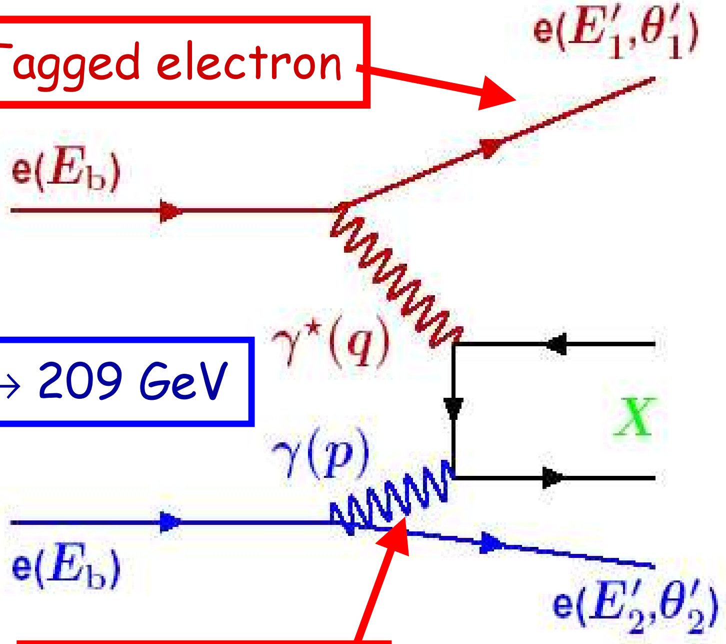


- Progress on measurements of F_2^γ using the full LEP statistics (DELPHI/ALEPH)
- Measurement of F_2^{charm} (OPAL)
- First measurement of the electron structure function F_2^e (DELPHI)
- New parton density parametrizations based on recent data and extraction of α_s
- Outlook & Future

Introduction: Kinematics

Measurements at LEP: Single tag two-photon interactions (DIS)

Tagged electron



Target photon

$\sqrt{s_{ee}}$ = 91 → 209 GeV

$$Q^2 = -q^2 = 2\,E_b\,E'_1\,(1-\cos\theta'_1)$$
$$f_y = 1 + (1-y)^2$$

$$x = \frac{Q^2}{Q^2 + W^2 + P^2}$$

Reconstruction of x needs hadronic final state

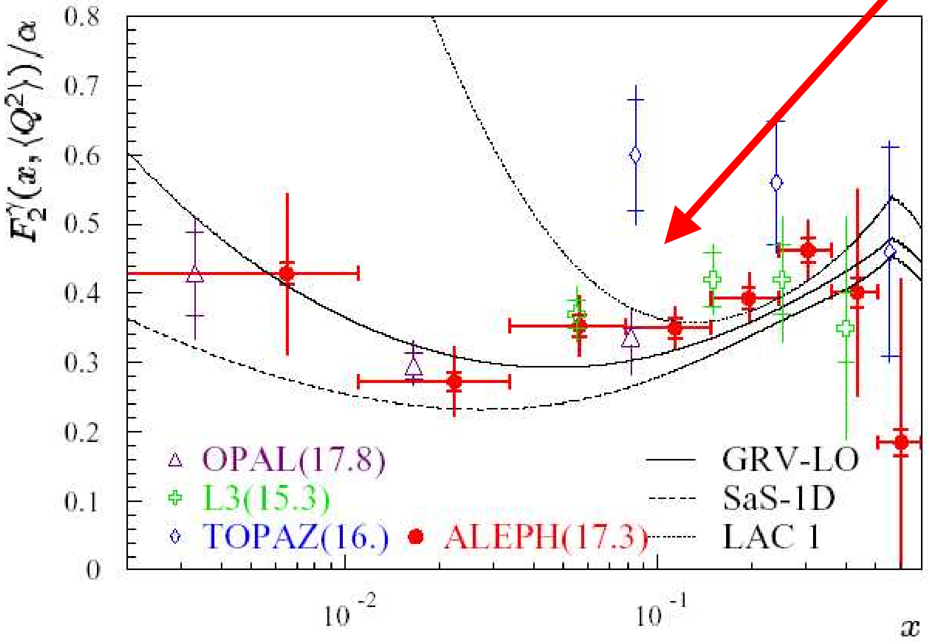
$$P^2 = -p^2 \ll Q^2$$

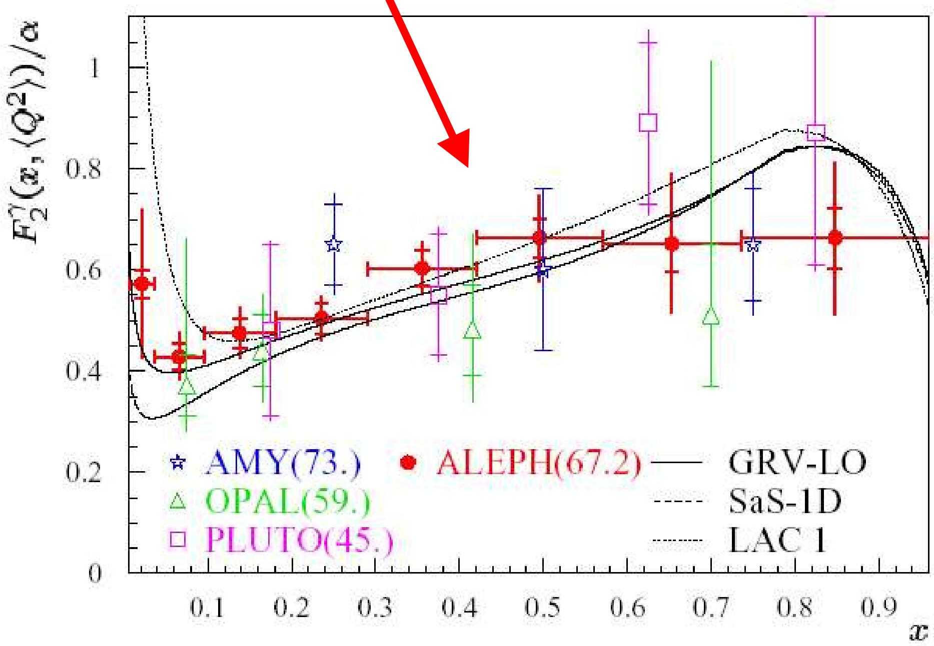
$$\frac{d^2 N_\gamma^T}{dz\,dP^2} = \frac{\alpha}{2\pi}\left[\frac{1+(1-z)^2}{z}\frac{1}{P^2} - \frac{2\,m_e^2\,z}{P^4}\right]$$

$$\frac{d^2\sigma_{e\gamma\to eX}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{x\,Q^4}\left[\left(1+(1-y)^2\right)F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2)\right]$$

New Data from ALEPH (preliminary)

LEP2 data from ALEPH based on 548.4 pb^{-1}
Tikhonov unfolding procedure used
Two ranges in Q^2: 17.3 GeV^2 and 67.3 GeV^2





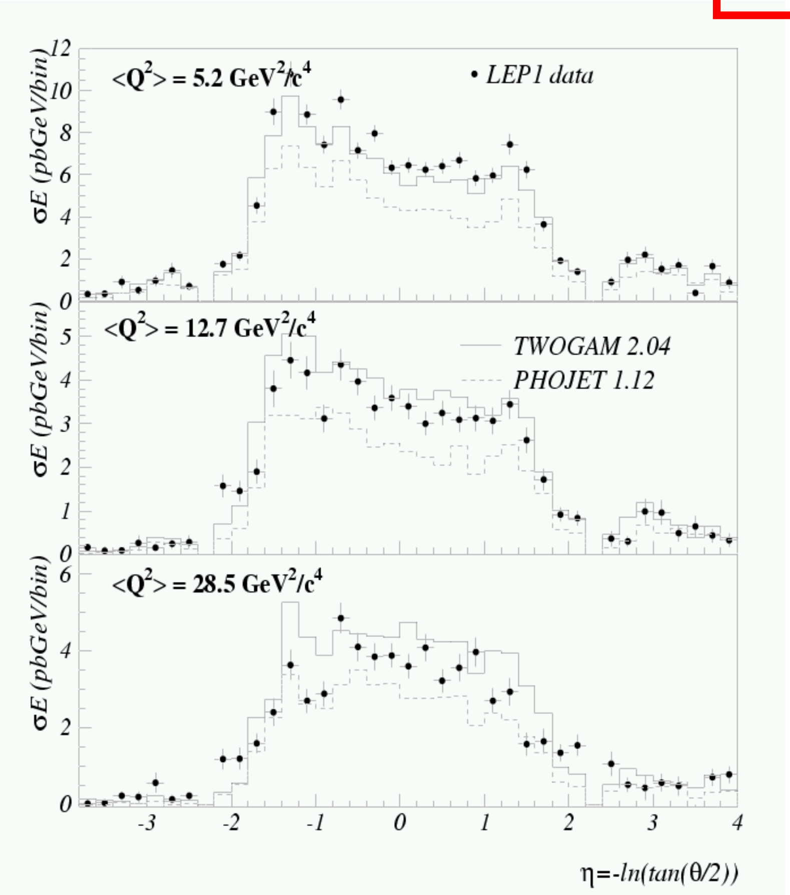
Comparison of F_2^γ for $x \geq 0.1$

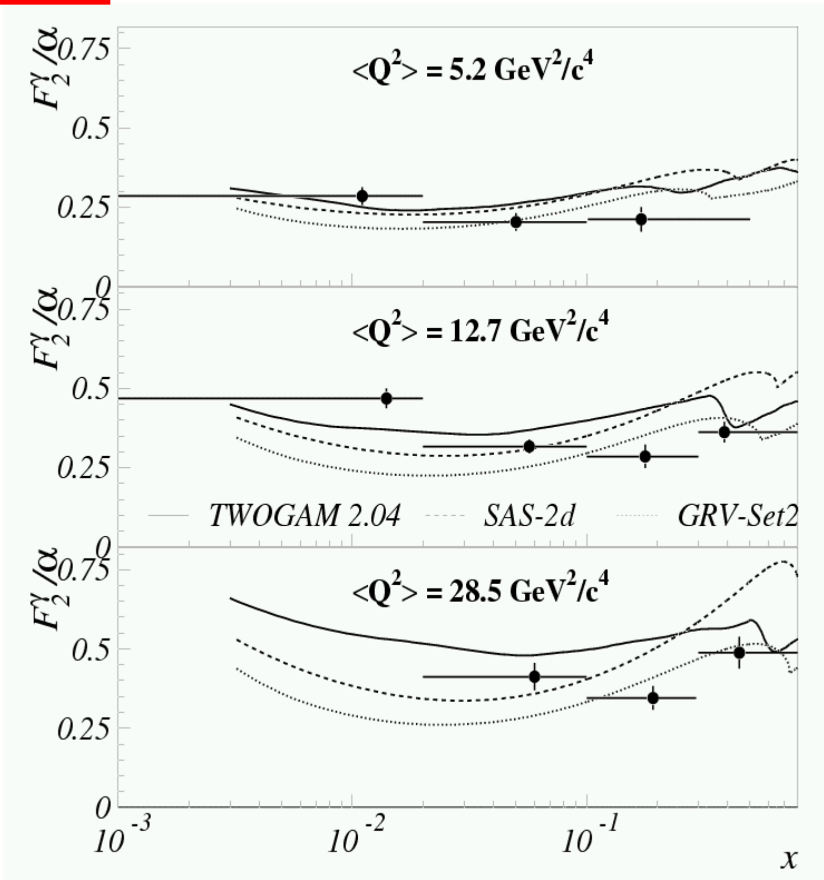
$$F_2^\gamma(0.1 \leq x \leq 0.5, \langle Q^2\rangle = 17.3\,\mathrm{GeV}^2) = 0.41 \pm 0.01\ (\mathrm{stat.}) \pm 0.08\ (\mathrm{sys.}),$$
$$F_2^\gamma(0.1 \leq x \leq 0.7, \langle Q^2\rangle = 67.2\,\mathrm{GeV}^2) = 0.52 \pm 0.01\ (\mathrm{stat.}) \pm 0.06\ (\mathrm{sys.}).$$

New Data from DELPHI

LEP1 and LEP2 data from DELPHI based on 78/548 pb^{-1}
No unfolding but fitting of different cross section components to data distributions

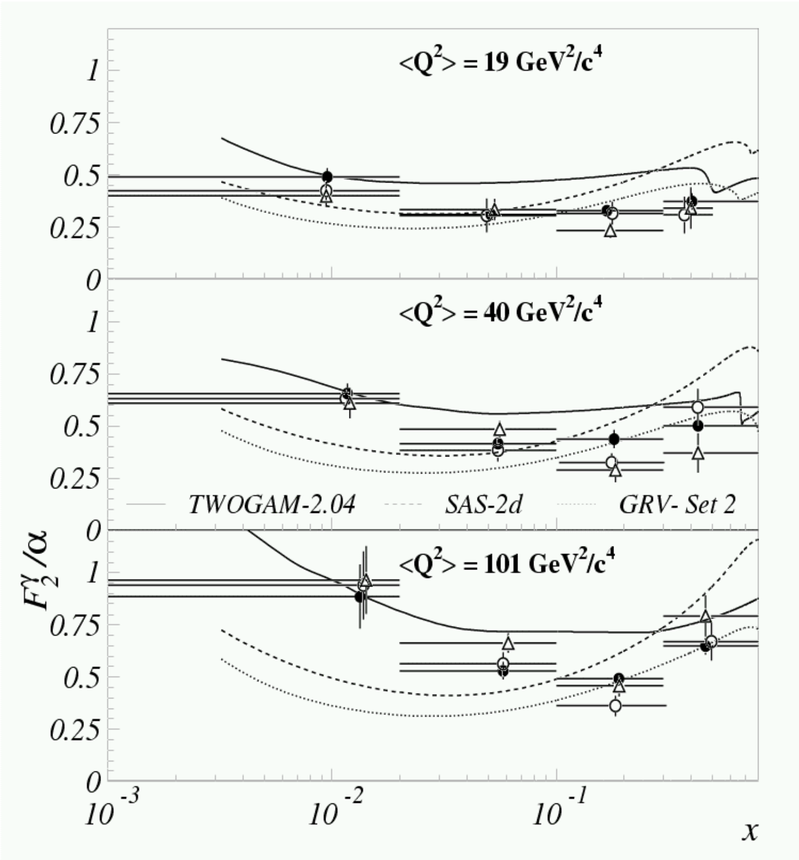
LEP1 data

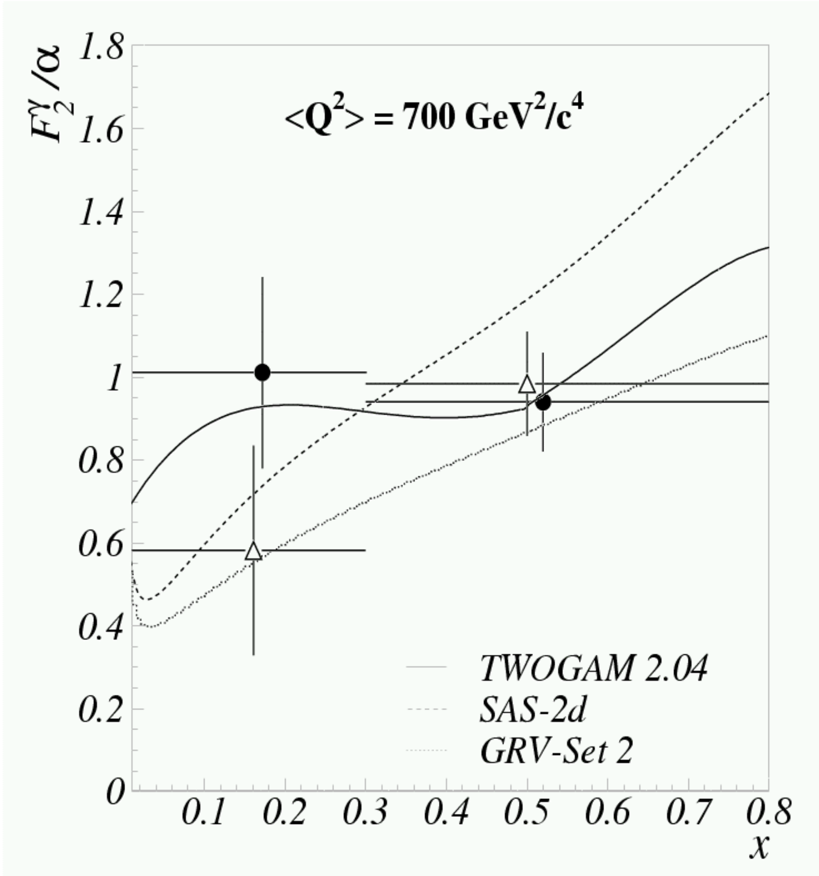




New Data from DELPHI

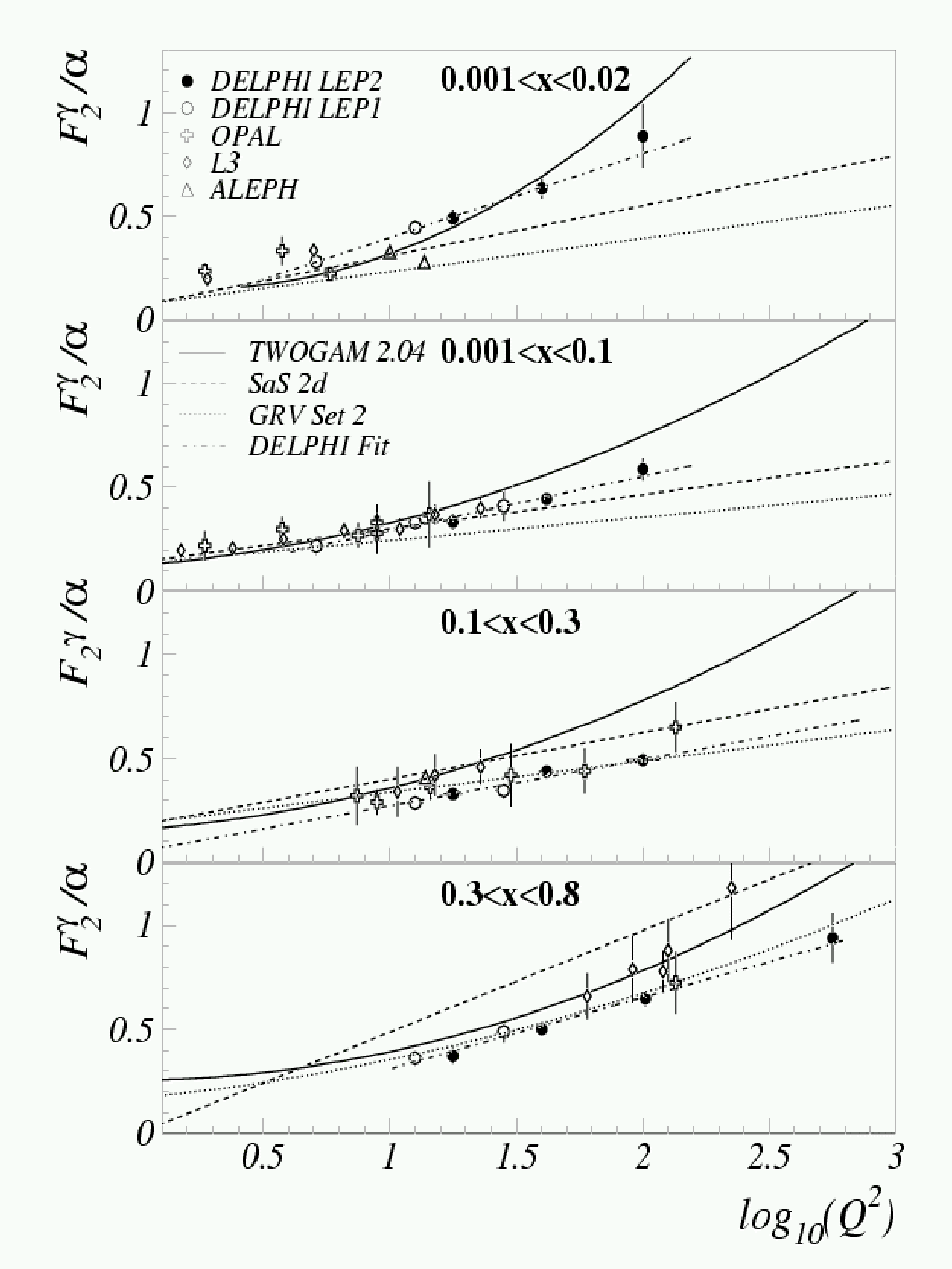
LEP2 data





Note: DELPHI chooses to present different F_2^γ values calculated/corrected with different hadronic models $\Rightarrow$difficult to compare with other LEP measurements

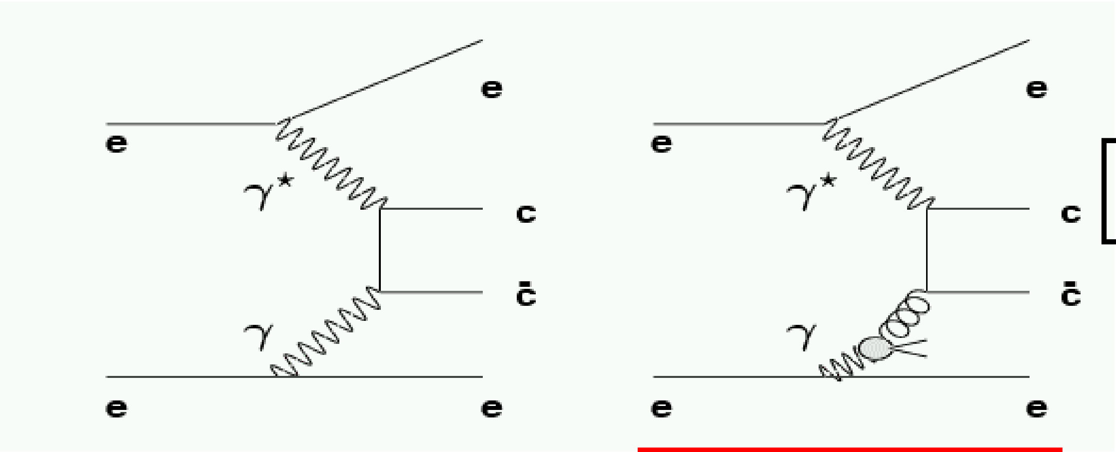
New Data from DELPHI



$\langle F_2^\gamma \rangle$ measurements in different x intervals as a function of $\langle Q^2 \rangle$

DELPHI points extracted using one model (TWOGAM) only.
Large spread due to different models not shown

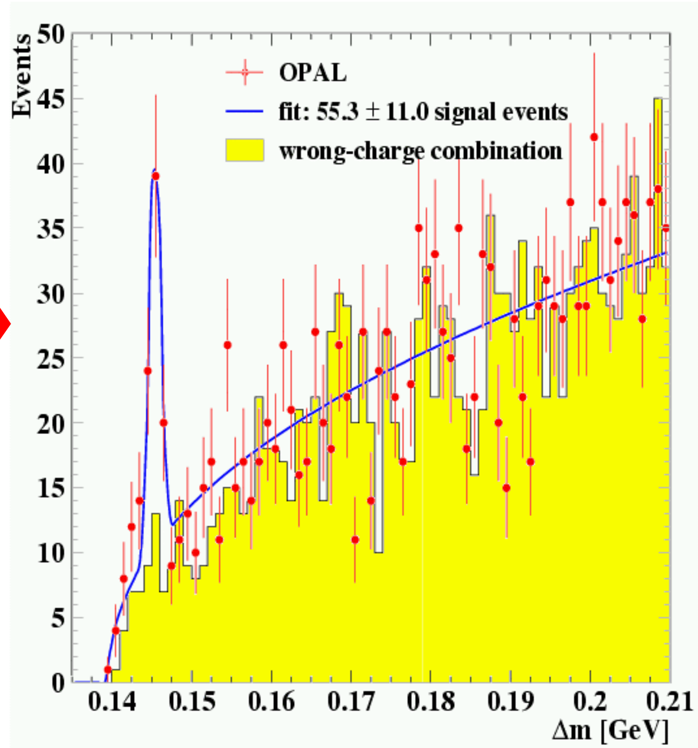
Data on F_2^{charm} from OPAL



Pointlike part (PQCD)

Hadron-like part depends on gluon in the photon

D*



Mass difference of $D^{\star+} \rightarrow D^0\pi^+$ and $D^0 \rightarrow K^-\pi^+(\pi^-\pi^+)$

$\mathcal{L} = 654.1\text{pb}^{-1}$ at $183 - 209$ GeV ($1997 - 2000$)

$\langle\sqrt{s_{ee}}\rangle = 196.6$ GeV

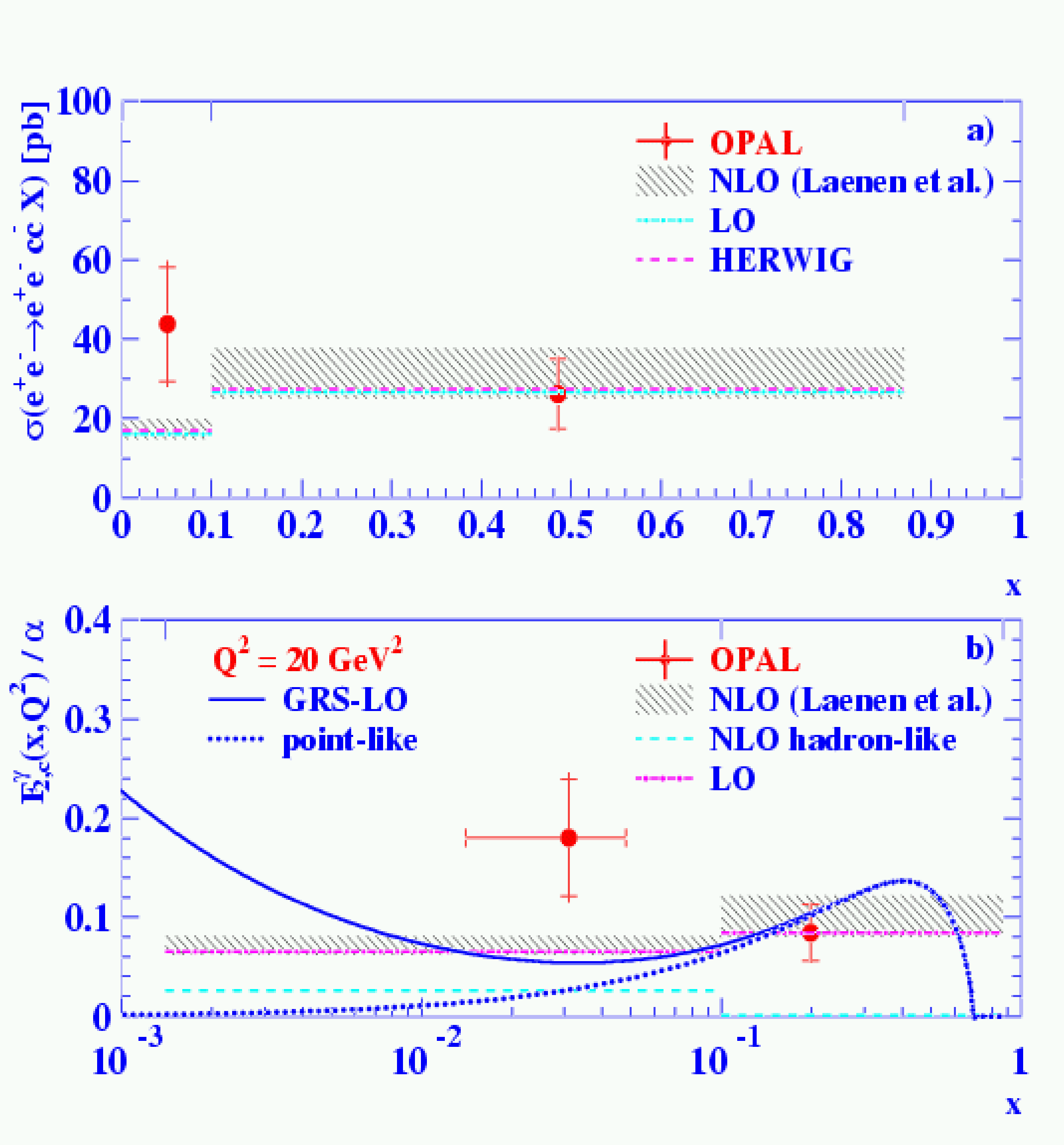
$5 < Q^2 < 100\ \text{GeV}^2$, $\langle Q^2\rangle \approx 20\ \text{GeV}^2$

55.3 ± 11.0 events

$x < 0.1$: 23.6 ± 7.4 events

$x > 0.1$: 31.4 ± 8.1 events

Data on F_2^{charm} from OPAL



Limited by statistics (data other LEP experiments?)

High-x: well described by PQCD calculation, essentially pointlike

Low-x: somewhat higher than Predicted but large error

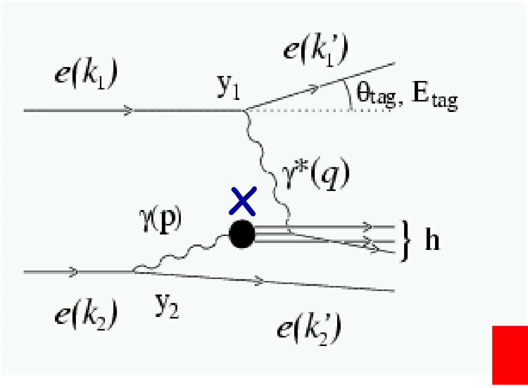
Subtract NLO pointlike part at low x

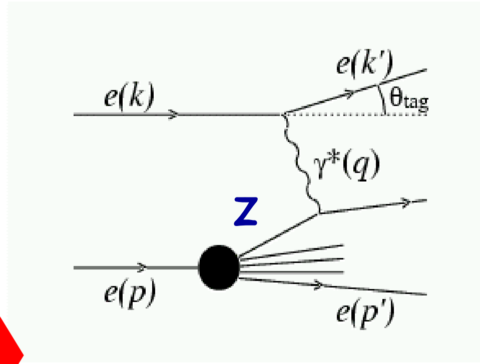
$$F_{2,c}^{\gamma,\mathrm{HL}} = 0.136 \pm 0.059 \pm 0.029$$

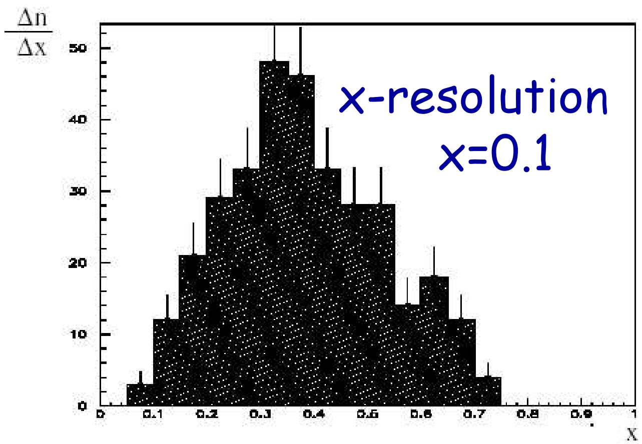
NLO prediction: $0.026^{+0.007}_{-0.005}$

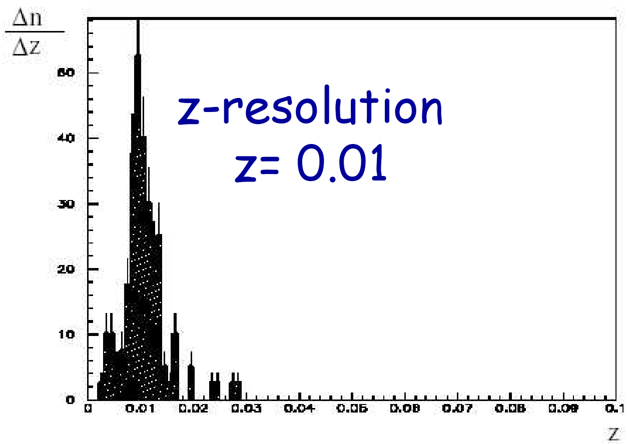
GRV-NLO/ Laenen et al.

Electron Structure Function









- Does not need hadronic final state to calculate x
  - ⇒ Kinematics better constrained
- No corrections due virtuality of the target photon (P) needed

- Photon flux spectrum obscures the sensitivity to the photon structure
- Radiative corrections large at small x

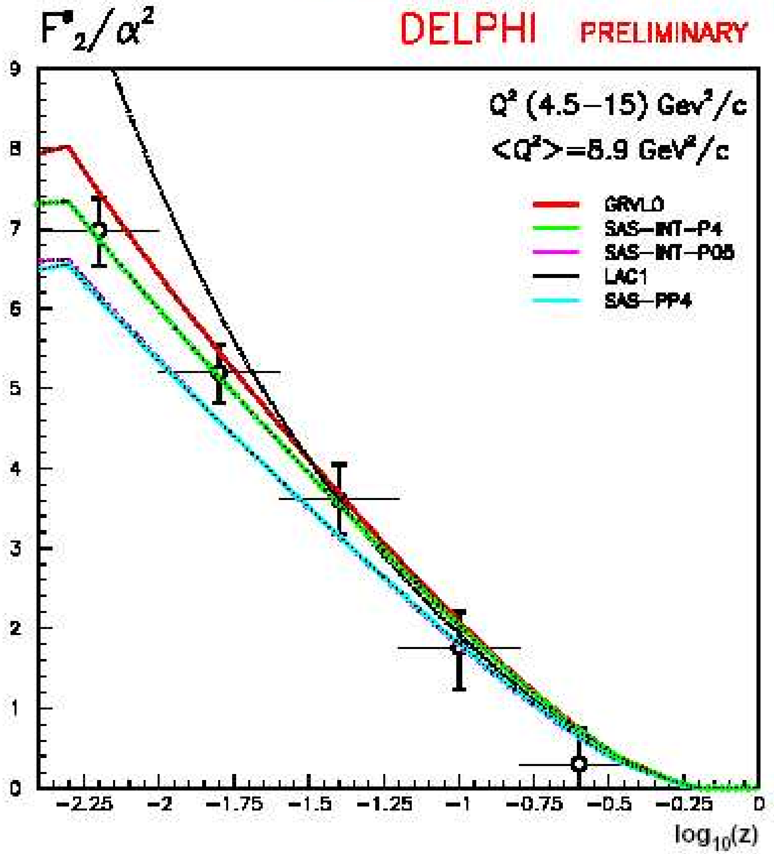
$$F_2^e(z, Q^2, P^2_{\max}) = \int_z^1 dy_\gamma \int_{P^2_{\min}}^{P^2_{\max}} dP^2 f_\gamma^e(y_\gamma, P^2)\, F_2^\gamma(z/y_\gamma, Q^2, P^2)$$

$$P^2_{\min} = m_e^2 y_\gamma^2/(1-y_\gamma).$$

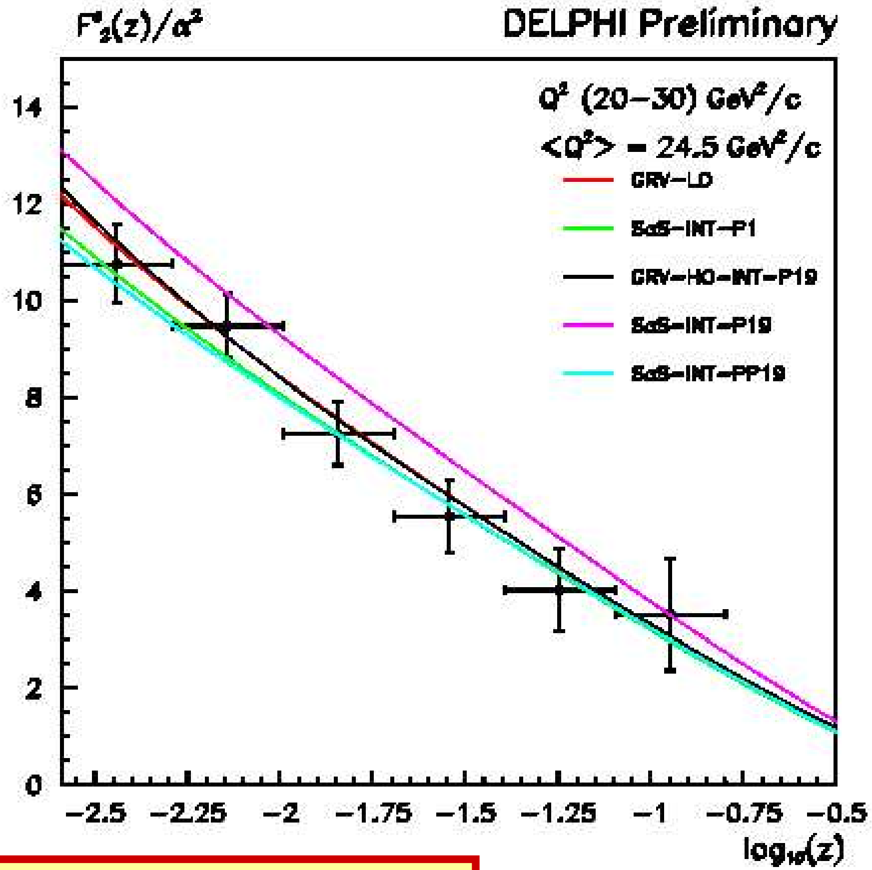
$$f_\gamma^e(y_\gamma, P^2) = \frac{\alpha}{2\pi P^2}\left[\frac{1+(1-y_\gamma^2)}{y_\gamma} - 2y_\gamma \frac{m_e^2}{P^2}\right]$$

Electron Structure Function

LEP1



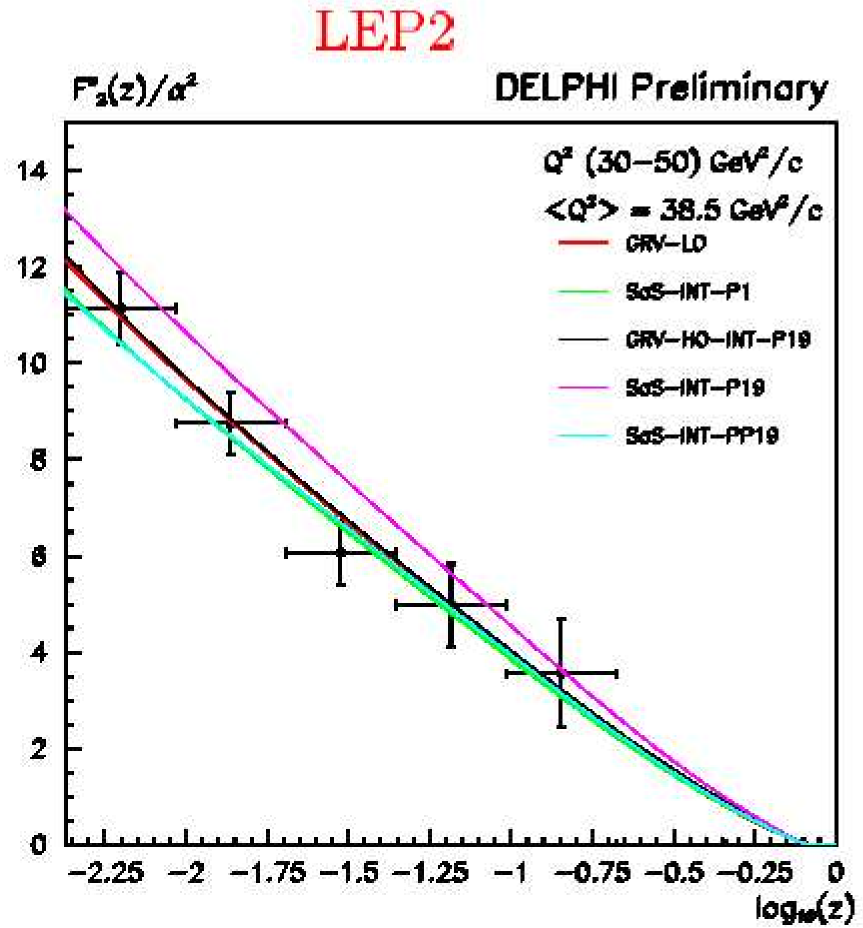
LEP2

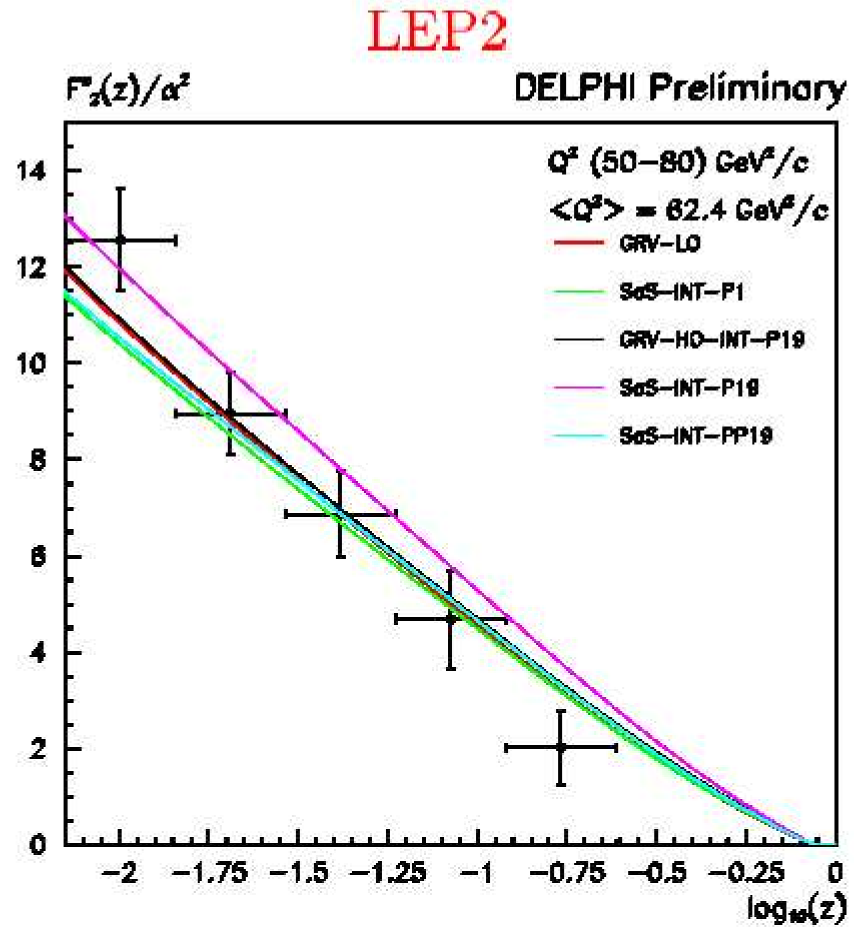


Measurements consistent with F_2^γ

Note: Real structure functions have to be "given" virtuality before comparing with F_2^e

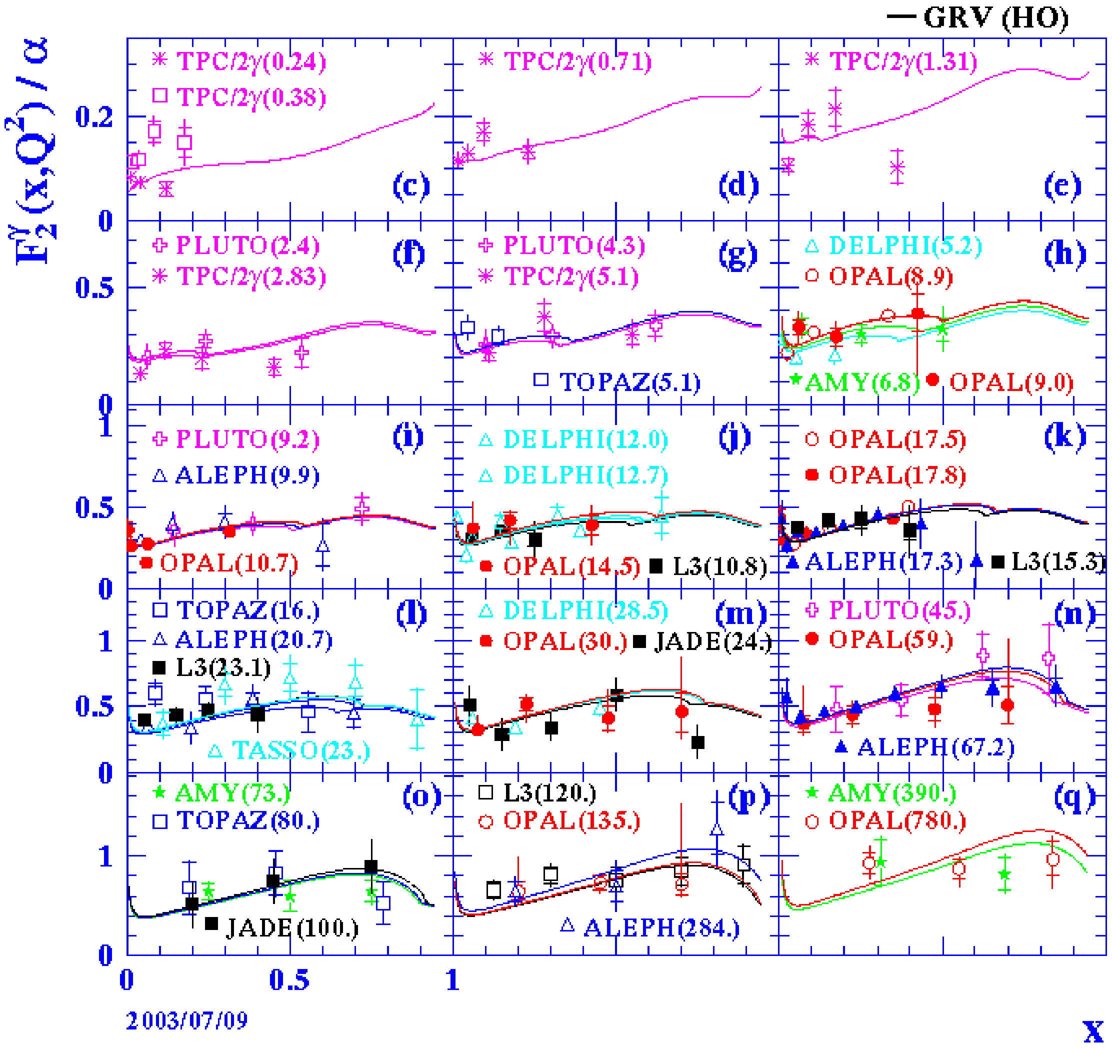
Electron Structure Function

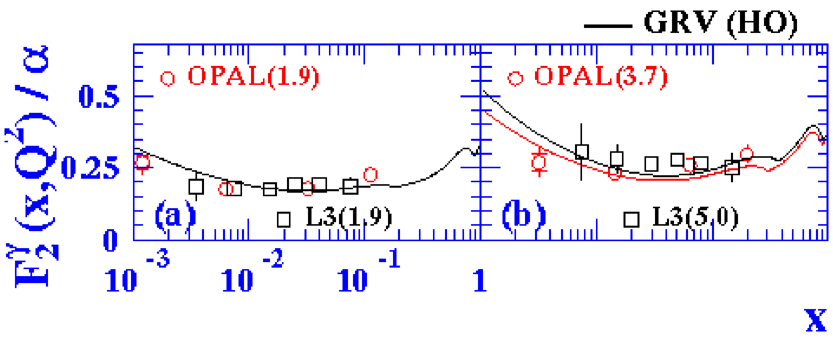




Measurements consistent with F_2^γ /reduced sensitivity

The World Data: F_2^γ versus x





More than 50 measurements

Kinematical coverage

$10^{-3} \leq x \leq 0.9$

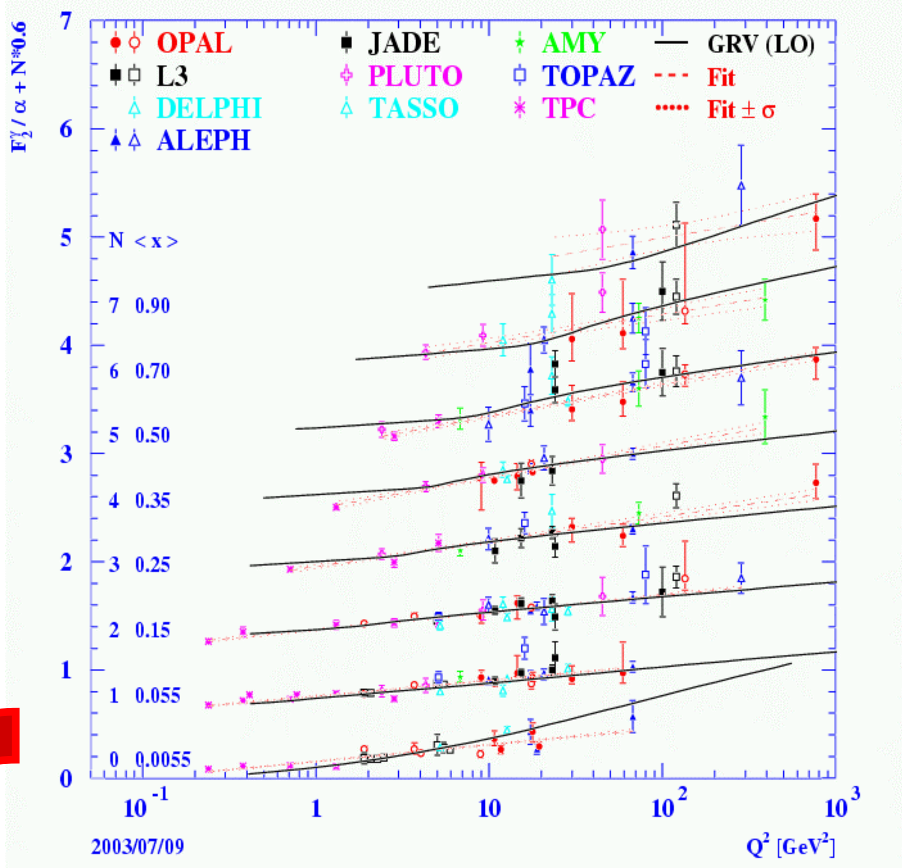
$1.9 \leq \langle Q^2 \rangle \leq 780\ GeV^2$

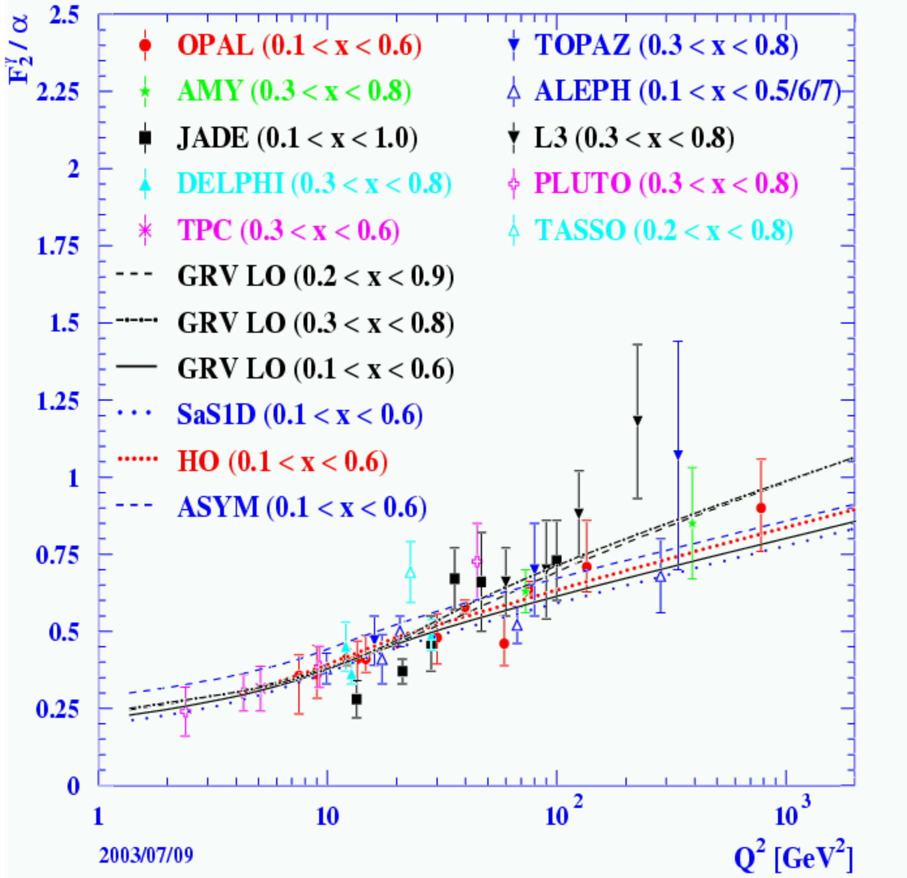
Used for new fits and the extraction of α_s

All except new DELPHI-LEP2 points

Thanks to R. Nisius, see http://www.mppmu.mpg.de/~nisius/welcomeaux/struc.html

The World Data: F_2^γ versus Q^2





Fit: $a + b\ln(Q^2/\Lambda^2)$

$\Lambda = 0.2\,\mathrm{GeV}$.

x bin	b-param
0.01–0.1	0.061 ± 0.003
0.2–0.3	0.095 ± 0.008
0.4–0.6	0.135 ± 0.013

Significant increase of the slope with increasing x

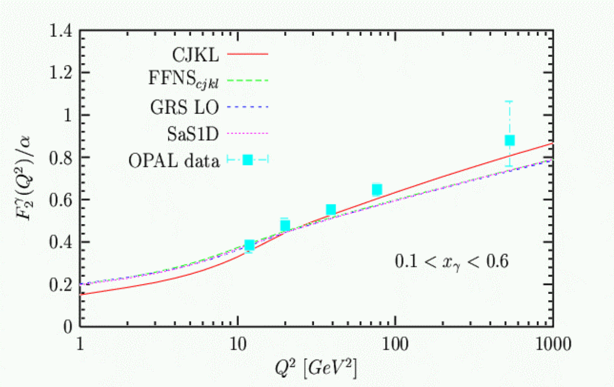
Parametrizations and Fits

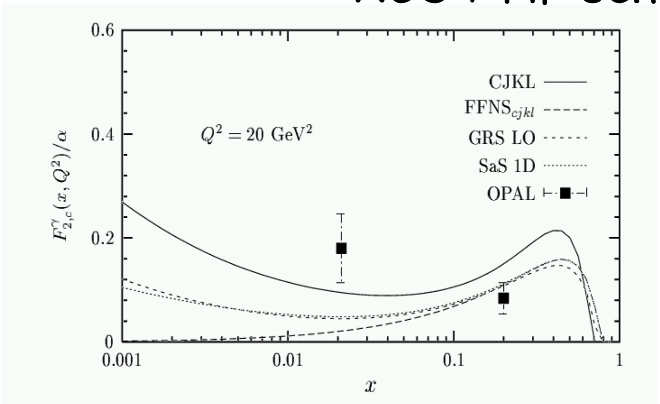
Parametrizations

Cornet, Jankowski, Krawczyk & Lorca, hep-ph/0212160

- New radiatively generated (LO) quark and gluon densities in the photon on all F_2^γ data available by summer 2002 (208 data points)
- NLO densities in progress…

ACOT HF scheme





Fit α_s from the F_2^γ data

Albino, Klasen & Soldner Rembold, hep-ph/0205069

Use data with (x>0.45, Q^2 > 59 GeV^2) and fit α_s

$$\alpha_s(M_Z^2) = 0.1183 \pm 0.0050(\text{exp.})^{+0.0029}_{-0.0028}(\text{theo.})$$

NLO/$\overline{\text{MS}}$

Use all data, 5 parameter fit for (N, α, β, α_s, Q_0^2)

$$\alpha_s(M_Z^2) = 0.1198 \pm 0.0028(\text{exp.})^{+0.0034}_{-0.0046}(\text{theo.})$$

Outlook I

Near Future

What can be still expected from the LEP experiments?

ALEPH: Possibly an analysis at larger Q^2

L3: Full analysis with all statistics

OPAL: Low-x, Q^2 analysis for F_2^γ and F_2^e

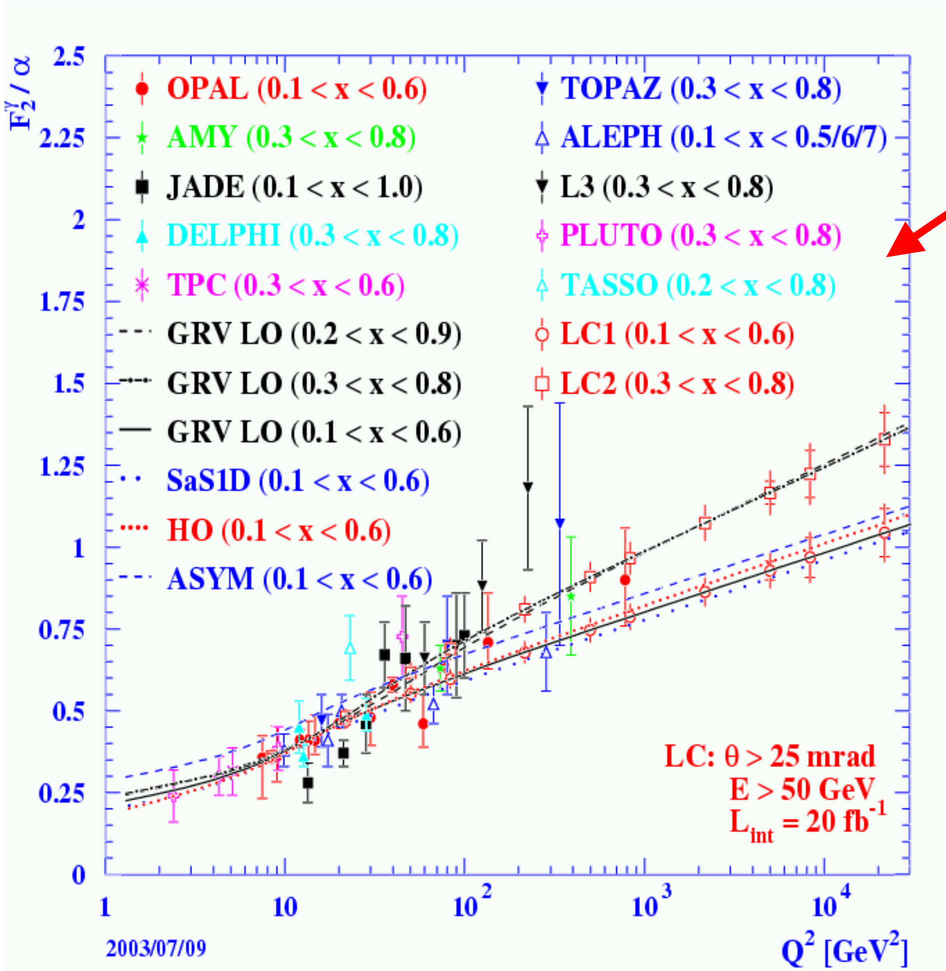
Outlook II

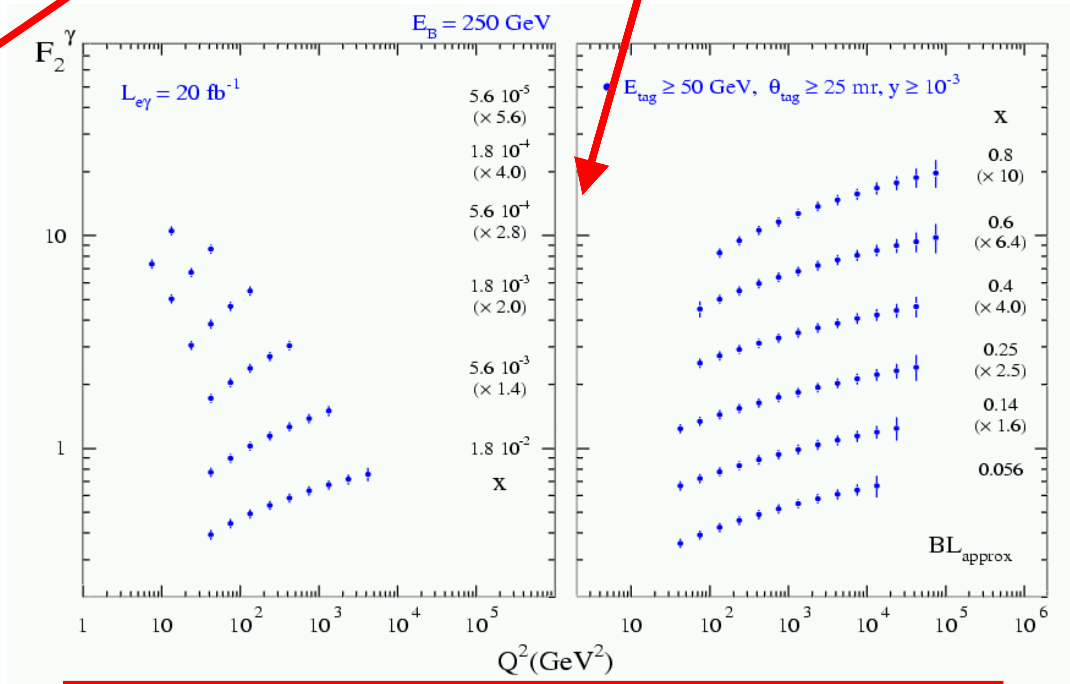
Far Future:

Large extension of the kinematic range at a future linear collider

e+e- option

Photon collider option





F_2^γ measurements with a quality similar to proton structure functions today !!

Summary

- The photon structure has now been investigated in a large range

$$10^{-3} \leq x \leq 0.9$$
$$1.9 \leq \langle Q^2 \rangle \leq \; 780 \text{ GeV}^2$$

- Precision has been improving over the years
- The charm content of the photon has been measured

  Will need data from the other 3 experiments
- The electron structure function has been measured, and serves as a valuable cross check of the photon structure function, but does not seem to add more discriminative power.
- New parametrizations of the parton densities in the photon become available. α_s values have been extracted from fits to the photon structure data.

Thanks to A. Finch, C. Mariotti, B. Muryn, R. Nisius, T. Szumlack, T. Wengler